

Essential idea: The mass of an atom is concentrated in its minute, positively charged nucleus.

2.1 The nuclear atom

Nature of science:

Evidence and improvements in instrumentation—alpha particles were used in the development of the nuclear model of the atom that was first proposed by Rutherford. (1.8)

Paradigm shifts—the subatomic particle theory of matter represents a paradigm shift in science that occurred in the late 1800s. (2.3)

Understandings:

- Atoms contain a positively charged dense nucleus composed of protons and neutrons (nucleons).
- Negatively charged electrons occupy the space outside the nucleus.
- The mass spectrometer is used to determine the relative atomic mass of an element from its isotopic composition.

Applications and skills:

- Use of the nuclear symbol notation A_ZX to deduce the number of protons, neutrons and electrons in atoms and ions.
- Calculations involving non-integer relative atomic masses and abundance of isotopes from given data, including mass spectra.

Guidance:

- Relative masses and charges of the subatomic particles should be known, actual values are given in section 4 of the data booklet. The mass of the electron can be considered negligible.
- Specific examples of isotopes need not be learned.
- The operation of the mass spectrometer is not required.

International-mindedness:

- Isotope enrichment uses physical properties to separate isotopes of uranium, and is employed in many countries as part of nuclear energy and weaponry programmes.

Theory of knowledge:

- Richard Feynman: “If all of scientific knowledge were to be destroyed and only one sentence passed on to the next generation, I believe it is that all things are made of atoms.” Are the models and theories which scientists create accurate descriptions of the natural world, or are they primarily useful interpretations for prediction, explanation and control of the natural world?
- No subatomic particles can be (or will be) directly observed. Which ways of knowing do we use to interpret indirect evidence, gained through the use of technology?

Utilization:

- Radioisotopes are used in nuclear medicine for diagnostics, treatment and research, as tracers in biochemical and pharmaceutical research, and as “chemical clocks” in geological and archaeological dating.
- PET (positron emission tomography) scanners give three-dimensional images of tracer concentration in the body, and can be used to detect cancers.

2.1 The nuclear atom

Syllabus and cross-curricular links:
Topics 11.3, 21.1 and options D.8 and D.9—NMR
Options C.3 and C.7—nuclear fission
Option D.8—nuclear medicine

Aims:

- **Aim 7:** Simulations of Rutherford's gold foil experiment can be undertaken.
- **Aim 8:** Radionuclides carry dangers to health due to their ionizing effects on cells.

Essential idea: The electron configuration of an atom can be deduced from its atomic number.

2.2 Electron configuration

Nature of science:

Developments in scientific research follow improvements in apparatus—the use of electricity and magnetism in Thomson’s cathode rays.(1.8)

Theories being superseded—quantum mechanics is among the most current models of the atom. (1.9)

Use theories to explain natural phenomena—line spectra explained by the Bohr model of the atom. (2.2)

Understandings:

- Emission spectra are produced when photons are emitted from atoms as excited electrons return to a lower energy level.
- The line emission spectrum of hydrogen provides evidence for the existence of electrons in discrete energy levels, which converge at higher energies.
- The main energy level or shell is given an integer number, n , and can hold a maximum number of electrons, $2n^2$.
- A more detailed model of the atom describes the division of the main energy level into s, p, d and f sub-levels of successively higher energies.
- Sub-levels contain a fixed number of orbitals, regions of space where there is a high probability of finding an electron.
- Each orbital has a defined energy state for a given electronic configuration and chemical environment and can hold two electrons of opposite spin.

Applications and skills:

- Description of the relationship between colour, wavelength, frequency and energy across the electromagnetic spectrum.
- Distinction between a continuous spectrum and a line spectrum.

International-mindedness:

- The European Organization for Nuclear Research (CERN) is run by its European member states (20 states in 2013), with involvements from scientists from many other countries. It operates the world’s largest particle physics research centre, including particle accelerators and detectors used to study the fundamental constituents of matter.

Theory of knowledge:

- Heisenberg’s Uncertainty Principle states that there is a theoretical limit to the precision with which we can know the momentum and the position of a particle. What are the implications of this for the limits of human knowledge?
- “One aim of the physical sciences has been to give an exact picture of the material world. One achievement ... has been to prove that this aim is unattainable.” —Jacob Bronowski. What are the implications of this claim for the aspirations of natural sciences in particular and for knowledge in general?

Utilization:

- Absorption and emission spectra are widely used in astronomy to analyse light from stars.
- Atomic absorption spectroscopy is a very sensitive means of determining the presence and concentration of metallic elements.

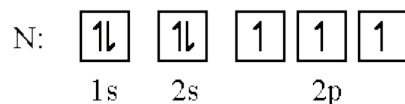
2.2 Electron configuration

- Description of the emission spectrum of the hydrogen atom, including the relationships between the lines and energy transitions to the first, second and third energy levels.
- Recognition of the shape of an s atomic orbital and the p_x , p_y and p_z atomic orbitals.
- Application of the Aufbau principle, Hund's rule and the Pauli exclusion principle to write electron configurations for atoms and ions up to $Z = 36$.

Guidance:

- Details of the electromagnetic spectrum are given in the data booklet in section 3.
- The names of the different series in the hydrogen line emission spectrum are not required.
- Full electron configurations (eg $1s^2 2s^2 2p^6 3s^2 3p^4$) and condensed electron configurations (eg $[\text{Ne}] 3s^2 3p^4$) should be covered.

Orbital diagrams should be used to represent the character and relative energy of orbitals. Orbital diagrams refer to arrow-in-box diagrams, such as the one given below.



- The electron configurations of Cr and Cu as exceptions should be covered.

- Fireworks—emission spectra.

Syllabus and cross-curricular links:

Topics 3.1 and 3.2—periodicity

Topic 4.1—deduction of formulae of ionic compounds

Topic 6.1—Maxwell–Boltzmann distribution as a probability density function

Physics topic 7.1 and option D.2—stellar characteristics

Aims:

- **Aim 6:** Emission spectra could be observed using discharge tubes of different gases and a spectroscope. Flame tests could be used to study spectra.